Video Article

Assessment of Age-related Changes in Cognitive Functions Using EmoCogMeter, a Novel Tablet-computer Based Approach

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Abstract

The main goal of this study was to assess the usability of a tablet-computer-based application (EmoCogMeter) in investigating the effects of age on cognitive functions across the lifespan in a sample of 378 healthy subjects (age range 18-89 years). Consistent with previous findings we found an age-related cognitive decline across a wide range of neuropsychological domains (memory, attention, executive functions), thereby proving the usability of our tablet-based application. Regardless of prior computer experience, subjects of all age groups were able to perform the tasks without instruction or feedback from an experimenter. Increased motivation and compliance proved to be beneficial for task performance, thereby potentially increasing the validity of the results. Our promising findings underline the great clinical and practical potential of a tablet-based application for detection and monitoring of cognitive dysfunction.

Video Link

The video component of this article can be found at http://www.jove.com/video/50942/

Introduction

Human aging is associated with cognitive decline in all domains, but might be particularly pronounced for functions associated with the prefrontal cortex and the medial temporal lobes, such as working memory (WM), episodic memory, and executive functions, (Bäckman *et al.*[1], Brehmer *et al.*[2], Shing *et al.*[3], West[4]). Correspondingly, brain-imaging studies showed that volume reductions are most prominent in prefrontal and mediotemporal areas (Raz *et al.*[5,6]) and that altered functioning within and between these regions might contribute to age-related cognitive changes (Sander *et al.*[7], Park and Reuter-Lorenz[8]). Molecular imaging studies indicate that age-related dopamine losses might be powerful mediators of impairment in multiple cognitive tasks (Bäckman *et al.*[9,10]; Erixon-Lindroth *et al.*[11], Volkow *et al.*[12]). There is considerable evidence that perceptive and cognitive competencies in old age might be enhanced by emotional stimuli. The tendency for older adults to perform better on positively valenced stimuli with regard to measures of attention, recognition, and emotional memory enhancement has been termed the age-related positivity effect (Charles *et al.*[13], Mather and Knight[14], Löckenhoff and Carstensen[15], Grühn *et al.*[16], Isaacowitz *et al.*[17]) and might reflect a difference in motivational goals as the end of life approaches (Carstensen and Löckenhoff[18]).

Neuropsychological testing of cognitive functions is usually conducted either by means of paper-and-pencil tests or computer-based tests on workstations, and might prove difficult when testing older subjects. Firstly, impaired motor skills might limit the use of paper-and-pencil tests and secondly, older subjects are often not familiar with keyboards, mouse pads, or other input devices applied during computer-based neuropsychological testing. As a result, older subjects often show poor motivation or compliance during neuropsychological testing, which might impair performance and decrease the validity of the findings. Furthermore, paper-and-pencil testing as well a computer-based testing on workstations requires permanent attendance of the experimenter for instruction and feedback as well as for documentation of results, which are then rarely transferred to a database and therefore only accessible to a very limited number of people. Thus, this "conventional" approach to neuropsychological testing ties up considerable human resources increases the probability of errors when transferring results, limits data access, and slows the workflow.

Our aim was to test a tablet-based application for the investigation of several neuropsychological domains. We used an iPad application as we hypothesized, that such a simple tool might be a quick and effective method to screen for and track cognitive deficits in clinical and outpatient settings. Regardless of age, subjects should be enabled to perform the tasks without instruction or feedback from an experimenter and should be able to complete the tests. Regardless of age, subjects should be enabled to perform the tasks without instruction or feedback from an experimenter. We hypothesized, that the touchpad would allow for a more intuitive use than other response devices (*e.g.* mouse pad or keyboard) particularly for older subjects, who are not familiar with computers. Heightened compliance and motivation for task performance might increase validity of results, while benefits for the experimenter should include a standardized and time saving testing procedure, a secure transfer of test results to a database and facilitation of data storage and analysis.

Protocol

1. Subjects

We recruited five hundred and forty-one psychologically and somatically healthy male and female subjects (age 44.47± 9.41; range 18-89 years; IQ 113.90±12.73). All subjects spoke German on a native speaker level. The study was carried out in accordance with the latest version of the Declaration of Helsinki and approved by the Institutional Review Board of the German Psychological Society. All subjects gave written informed consent before screening and were reimbursed for participation.

2. Study Design

The EmoCogMeter, an iPad-based application, includes 7 neuropsychological tests and was developed to investigate cognitive functions in several domains. Prior to each test, a short instruction and demonstration was displayed on the screen. There was no verbal instruction or feedback from the experimenter. Subjects needed approximately 25-30 min to complete the testing session.

1. **Neuropsychological Tests**
    1. Learning and memory
        1. *Memory Span*

            Present the participants with a series of digits and ask them to input the numbers immediately afterwards. Start with 2 digits and if participants are successful, give a longer list of numbers.
            1. End the task either after 5 min, or earlier, if subjects successfully recall 9 digits. Record the digit span and the number of total trials required to reach that level.
        2. *Working Memory*

            Have participants view sequences of positive, negative and neutral words and respond if a word is the same as the one presented two trials before.
            1. End the task after 5 min and record the number of correct responses (hits), false responses, and the mean latency of responses.
    2. Attention and concentration
        1. *Selective Attention*

            Apply a variant of the Stroop task and ask subjects to respond if the written color name corresponds to the color ink it was displayed in.
            1. End the task after 3 min and record the number of correct responses (hits), false responses, missed responses, and the mean latency of responses.
        2. *Sustained Attention*

            Use a task that includes a small working memory component. Present a circle consisting of small blue and yellow circles, illuminated in a pseudo-random order in the center of the screen.
            1. Instruct subjects to detect and respond to sequences of blue-yellow-yellow. End the task after 4 min and record the number of correct responses (hits), false responses, and missed responses.
    3. Executive Functions
        1. *Trail Making Test B*

            Probe task switching and require subjects to sequentially and alternatively connect 13 numbers and 12 letters on the screen. Do not display the connection if the subject made an error and do not continue the task before the correct connection is selected.
            1. End the task after 90 sec if it is not successfully completed until then. Record the total time required to complete the task.
        2. *Tower of Hanoi*

            Assess planning and the ability to achieve a goal through a series of intermediate steps. Use a version with three rods and four discs of subsequently smaller size.
            1. Inform subjects that they have to move the entire stack of discs to another rod by obeying the following rules: (1) Only one disk may be moved at a time. (2) Each move consists of taking the upper disk from one of the rods and sliding it onto another rod, on top of the other disks that may already be present on that rod. (3) No disk may be placed on top of a smaller disk.

2. End the test if subjects fail to reach the goal after 4 min. Record the time needed to solve the task and the number of moves required for solution.

4. Processing Speed

Symbol Letter Modalities Test

Present subjects with 9 letters and corresponding geometric symbols in the upper part of the screen. Display rows of letters in the lower part and instruct subjects to move the corresponding symbol under each letter as fast as possible.
1. Record the number of correct responses (hits), false responses, missed responses and the mean latency of responses within the allowed time (90 sec).

2. **Statistical analysis**

For the tests probing working memory, selective attention and sustained attention we defined an accuracy ratio ((hits- false)/ targets) x 100. All data were analyzed using multivariate analyses of variance (MANOVAs) with the between-subjects factors age group and gender. GreenhouseGeisser corrections were applied where appropriate. If MANOVAs revealed significant main or interaction effects, further statistical analyses were conducted using t-test comparisons.

Representative Results

Data from 19 subjects could not be recorded due to technical problems. All remaining subjects (N= 522) completed the tests and were clustered into 3 age groups (young: 18-30 years; middle-aged: 31-59 years; old: 60-89 years). Participants in these groups were matched according to gender and IQ resulting in a sample size of N= 378 (see **Table 1**). Performance for all neuropsychological tests in the 3 age groups is summarized in **Table 2**.

Learning and memory

Memory Span

There was a main effect of age on digit span ($F(2)=15.99$, $p= .000$) with lower digit span in old compared to young ($p< 0.01$) as well as to middle-aged subjects ($p< 0.01$) (see **Figure 5**). There were no differences between young and middle-aged subjects. Age groups did not differ in the number of total trials needed and there was no effect of gender on memory span.

Working Memory

There was a main effect of age on accuracy ($F(2)=21.19$, $p= .000$) with significantly lower accuracy in old compared to young ($p< 0.01$) as well as to middle-aged subjects ($p< 0.01$) regardless of stimulus valence (see **Figure 6**). There were no differences between young and middle-aged subjects and no effect of gender.

Regarding the reaction times there were main effects of age ($F(2)=30.31$, $p= .000$) and gender ($F(2)=18.34$, $p= .000$) as well as a gender by age interaction ($F(2)=11.93$, $p= .000$) regardless of stimulus valence. Post hoc t-tests revealed a continuous increase in reaction times across the lifespan only in women, with significant longer reaction times in middle-aged compared to young ($p< 0.05$) and old compared to middle-aged subjects ($p< 0.01$). In men, middle-aged subjects had shorter reaction times than young ($p< 0.01$) and also than old subjects ($p< 0.01$). While there were no gender differences in the young subjects, middle-aged women were significantly slower ($p< 0.01$) than men regardless of stimulus valence. In old subjects only reaction times for negative words were slower in women ($p< 0.05$) (see **Figure 7**).

Attention and concentration

Selective Attention

Age had a significant main effect on accuracy ($F(2)=31.52$, $p= .000$) with a decline between middle and old age ($p< 0.01$) (see **Figure 8**). There was no effect of gender on selection accuracy.

Sustained Attention

There was a main effect of age on accuracy ($F(2)=38.69$, $p= .000$) with a continuous decline from young to middle ($p< 0.01$) and middle to old age ($p< 0.01$) (see **Figure 9**). Gender had no effect on accuracy.

Executive Functions

Trail Making Test B

The ANOVA showed a significant main effect of age on the time required to complete the task ($F(2)=23.44$, $p= .000$), which continuously increased across the lifespan (young vs. middle-aged: $p< 0.01$; middle-aged vs. old: $p< 0.01$) (see **Figure 10**). There was no effect of gender.

Tower of Hanoi

There was a main effect of age on the time needed to solve the task ($F(2)=41.60$, $p= .000$). Posthoc ttests showed that solution time continuously increased across the lifespan (young vs. middle-aged: $p< 0.05$; middle-aged vs. old: $p< 0.01$) (see **Figure 11**). Furthermore, there was a main effect of gender on solution time (F(2)=7.88, p= .005) with women needing more time than men in all age groups. Age and gender had no effect on the number of moves required for solution.

Processing Speed

Symbol Letter Modalities Test

Age had a significant main effect on the number of letters correctly matched with geometric forms (F(2)=122.55, p= .000), which continuously decreased across the lifespan (young vs. middle-aged: p< 0.01; middle-aged vs. old: p< 0.01) (see **Figure 12**).

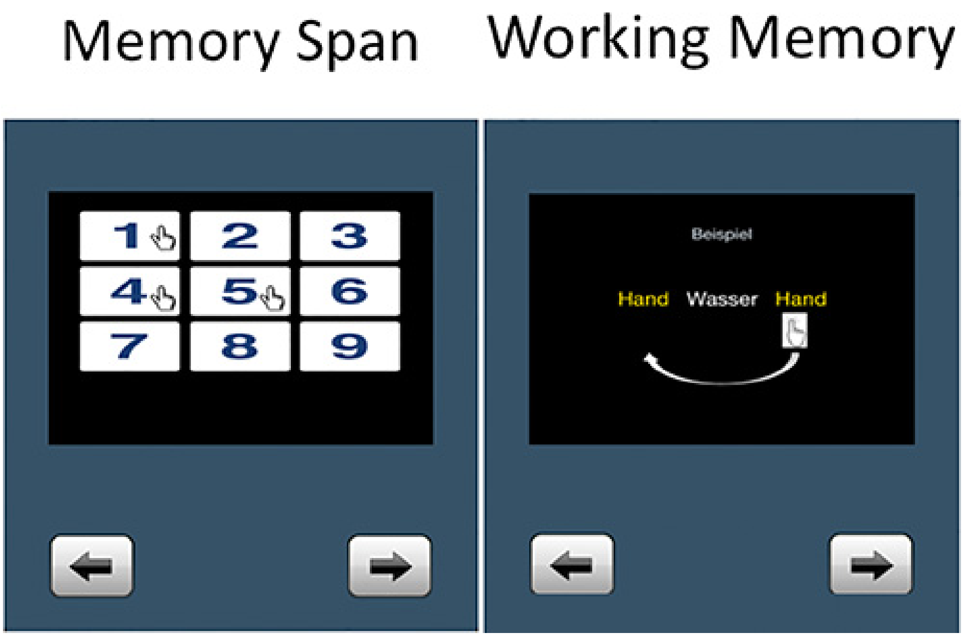

Figure 1. Illustration of tasks on memory span and working memory.

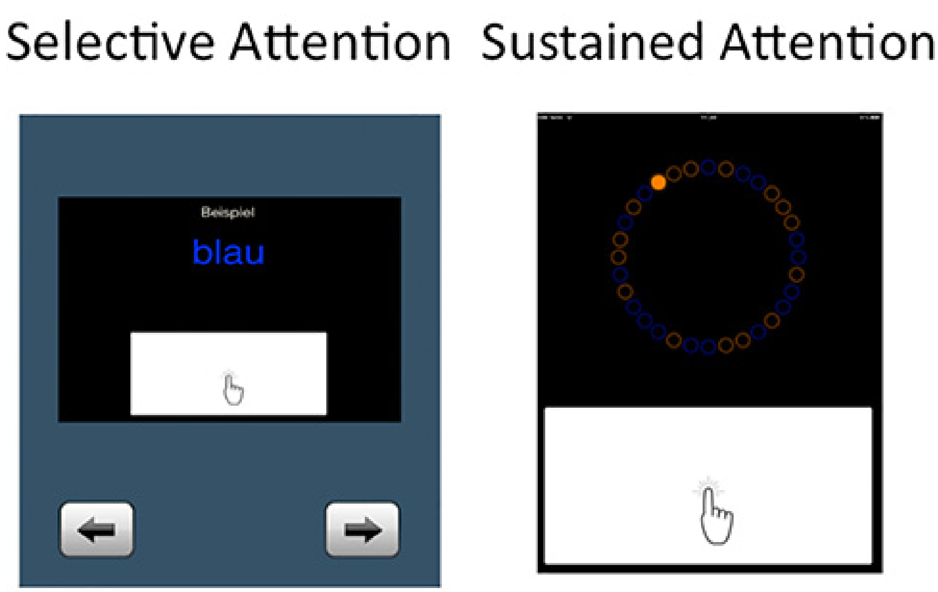

Figure 2. Illustration of tasks on selective and sustained attention.

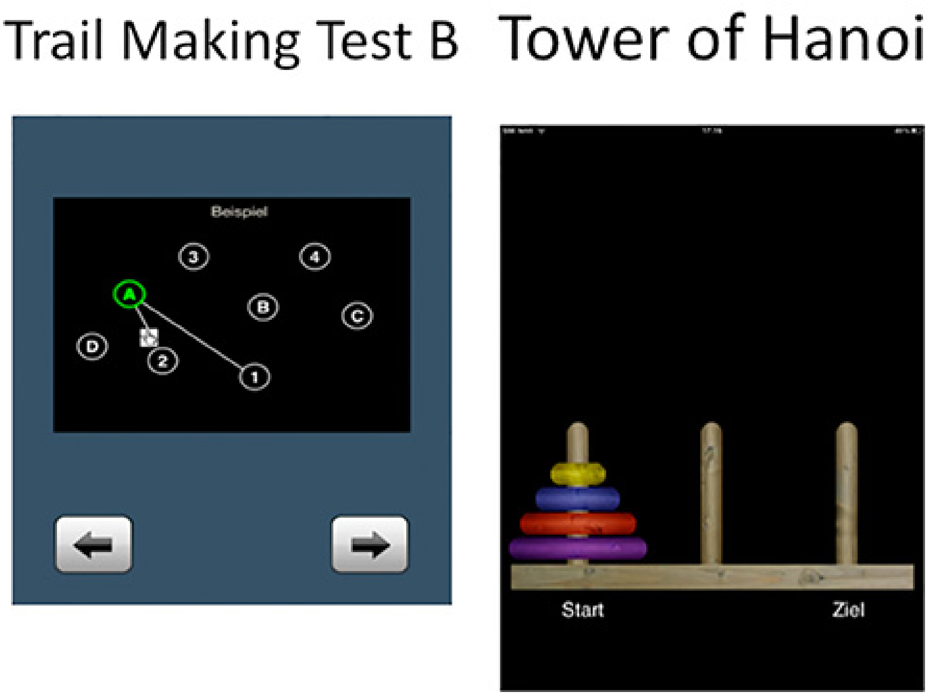

Figure 3. Illustration of Trail Making Test B and Tower of Hanoi task.

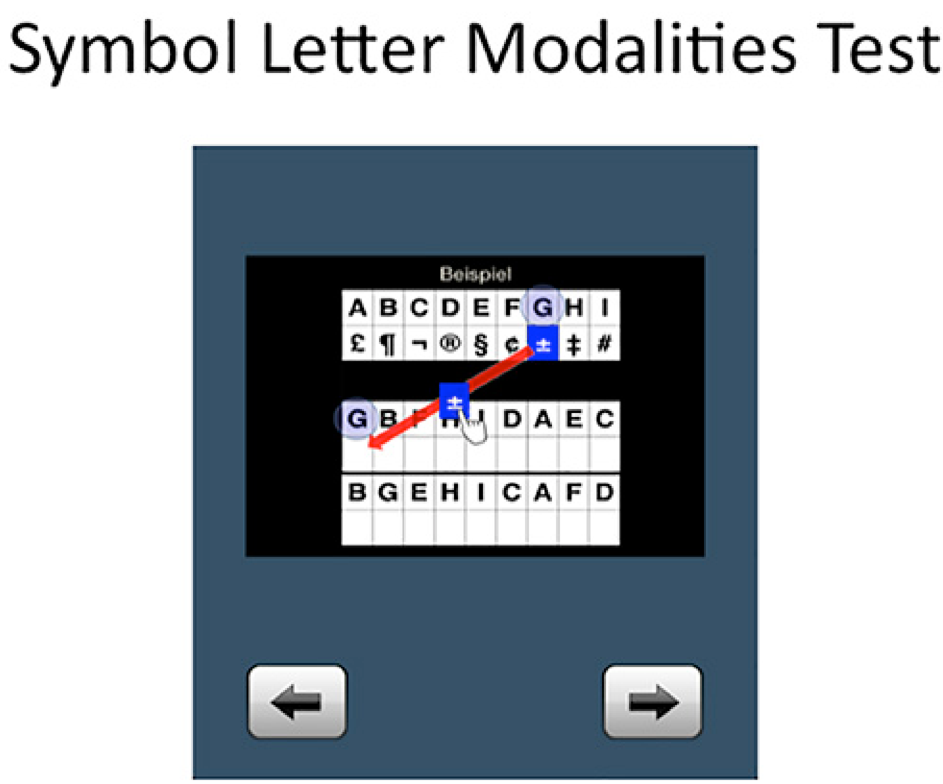

Figure 4. Illustration of Symbol Letter Modalities Test.

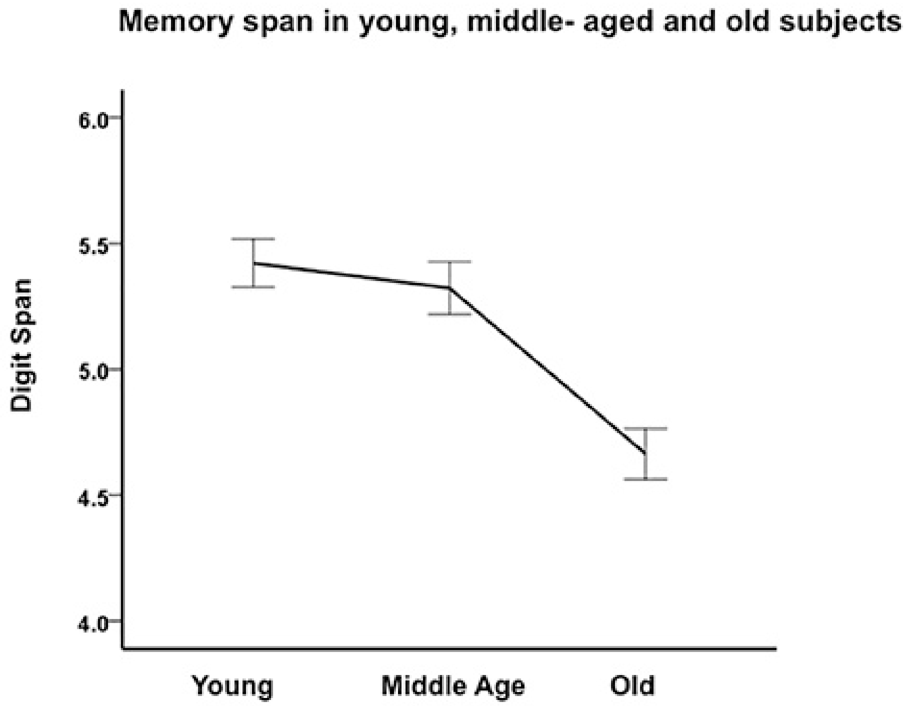

Figure 5. Memory span in young, middle-aged and old subjects.

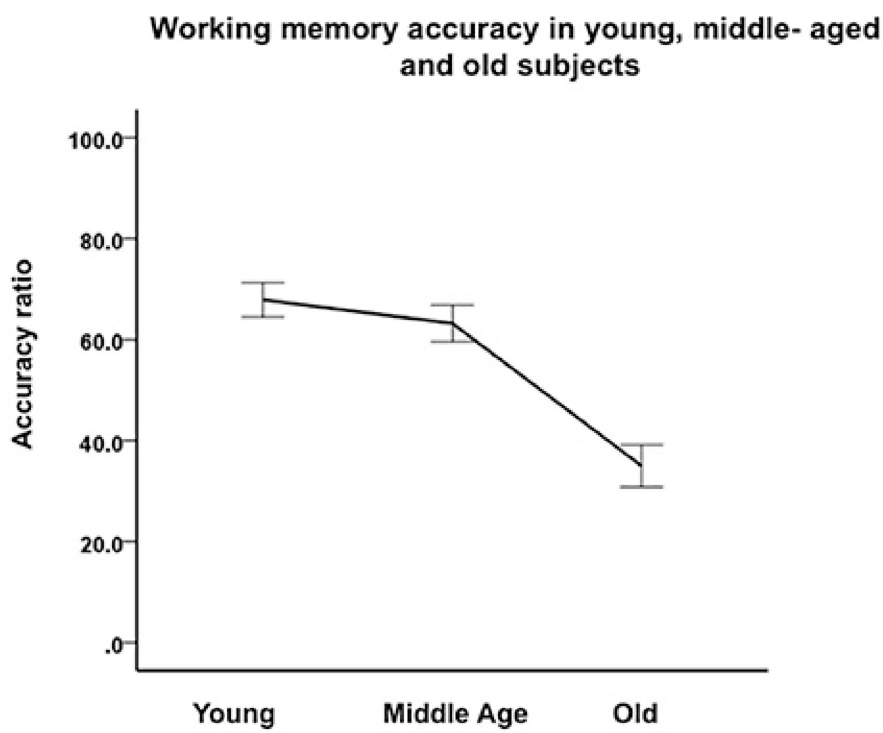

Figure 6. Working memory accuracy in young, middle-aged and old subjects.

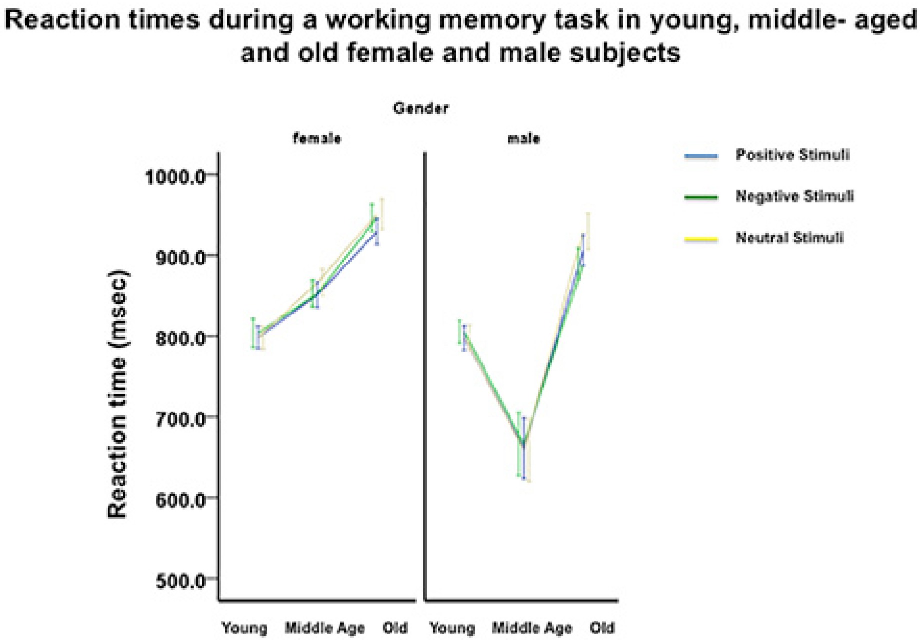

Figure 7. Reaction times during a working memory task in young, middle-aged and old female and male subjects.

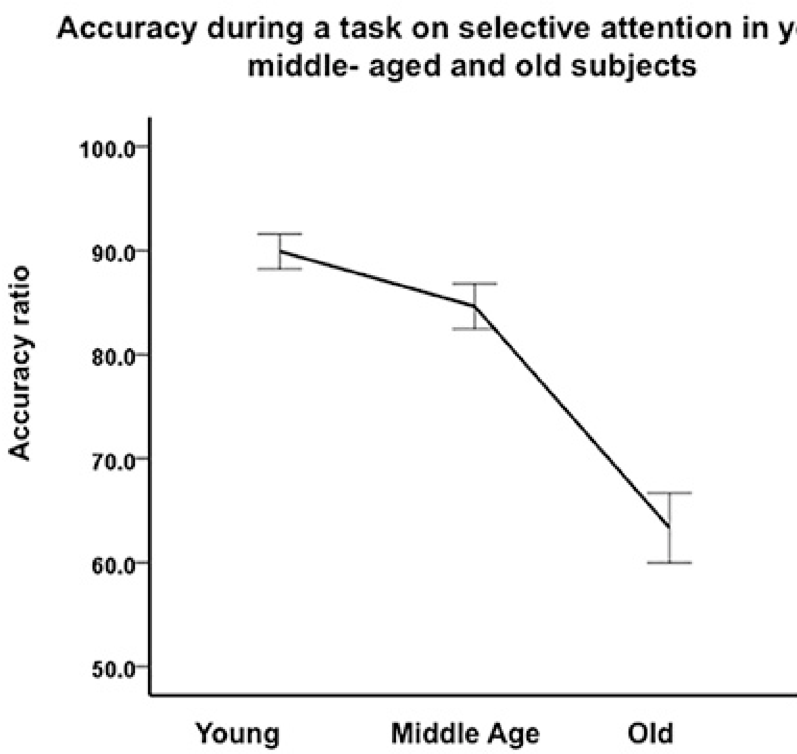

Figure 8. Accuracy during a task on selective attention in young, middle-aged and old subjects.

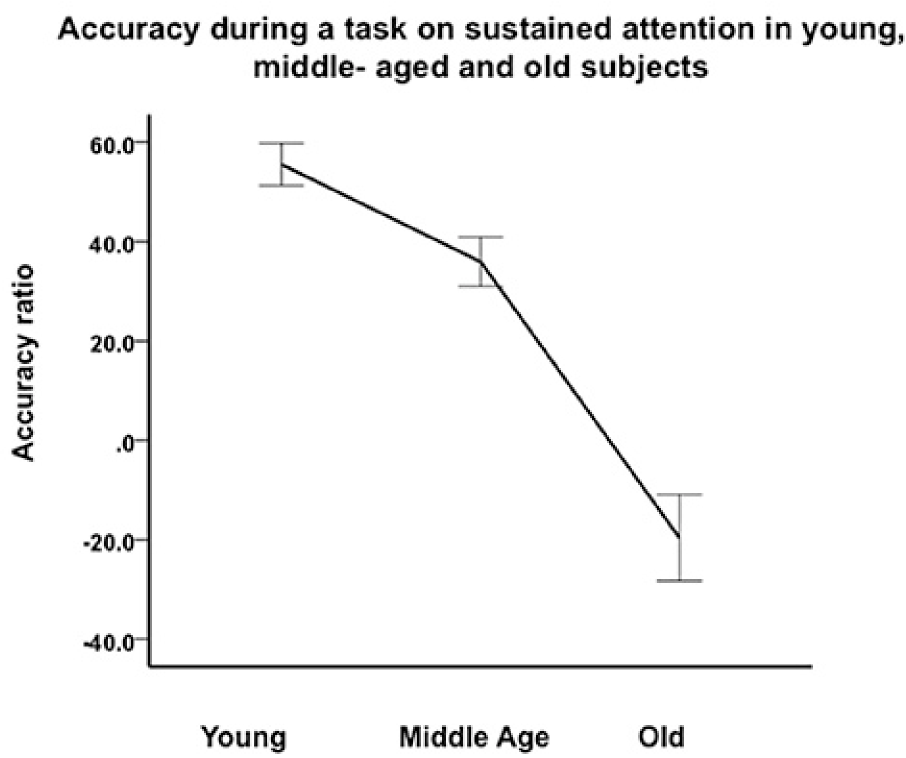

Figure 9. Accuracy during a task on sustained attention in young, middle-aged and old subjects.

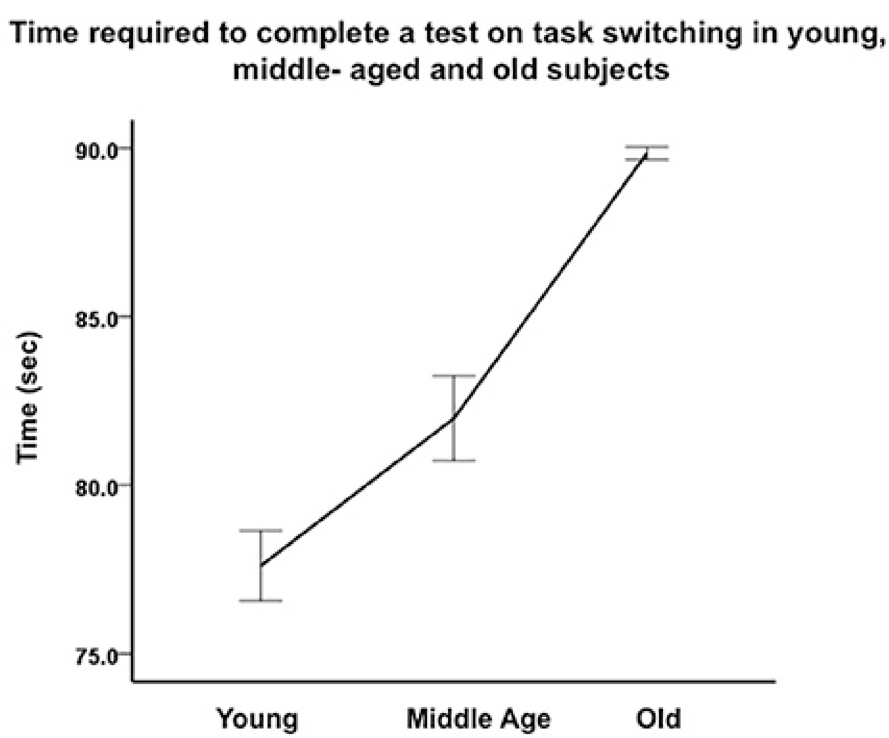

Figure 10. Time required to complete a test on task switching in young, middle-aged and old subjects.

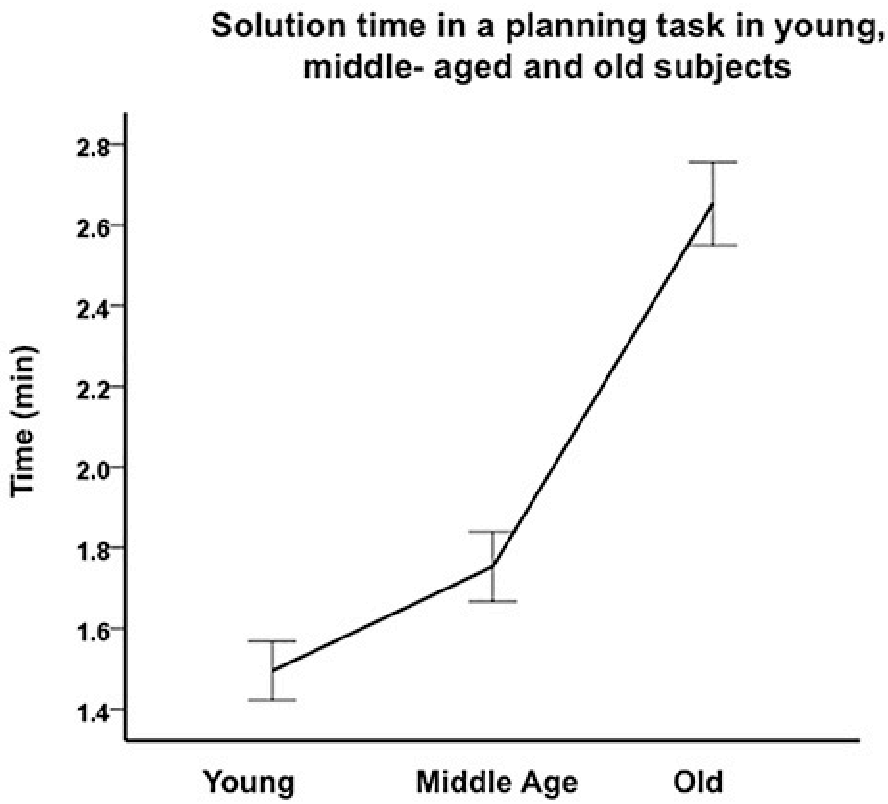

Figure 11. Solution time in a planning task in young, middle-aged and old subjects.

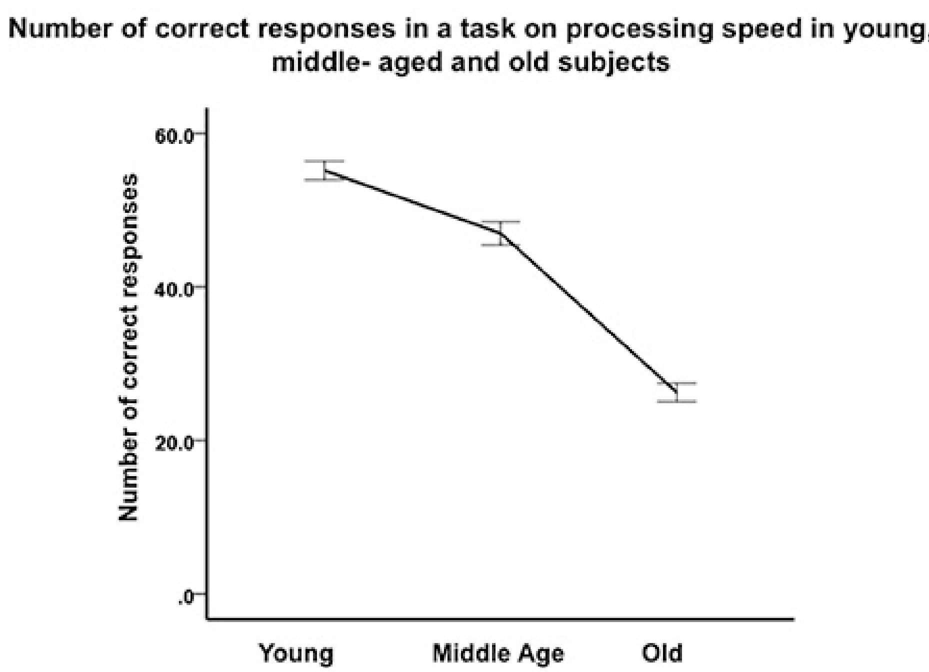

Figure 12. Number of correct responses in a task on processing speed in young, middle-aged and old subjects.

Discussion

The main goal of this study was to assess the usability of a tablet-computer based application in investigating the effects of age on cognitive functions across lifespan. As hypothesized, subjects showed an age-related decline in most neuropsychological domains. For some cognitive functions, such as memory span, working memory accuracy, and selective attention, the decline appears to occur later in life, as it was only observed when comparing middle-aged and old subjects. Other cognitive functions, mainly response latency, sustained attention, processing speed and executive functions already seem to be affected in middle-age. Gender effects were observed on reaction times during a working memory task, with a continuous increase in reaction times across lifespan only in women, while reaction times in middle-aged men appear to be shorter than in young as well as in old men. Longer reaction times in old women than men were only observed for negative, but not for positive or neutral stimuli. Also, women showed slowed cognitive planning regardless of age.

Our findings confirm previous results of an age-related decline across a wide range of cognitive abilities (Baltes and Lindenberger[19], Craik and Rose[20], Hayden *et al.*[21]). Changes in memory function might be mediated by reductions in white-matter integrity and volume in medio-temporal areas occurring later in life (Raz *et al.*[5,6]). Executive functions, attention and processing speed rely more on the integrity of the prefrontal cortex and connectivity between brain regions and appear to be affected earlier (Sander *et al.*[7], Park and Reuter-Lorenz[8]).

However, when assessing executive function regardless of speed, older subjects were unimpaired, suggesting a specific age-effect on the speed component of the planning task. Here, subjects might have been slower either due to motor impairments or to more thorough strategic planning. Early cognitive changes might also be related to the continuous decline of dopamine systems from early to late adulthood (Bäckman *et al.*[9,10], Erixon-Lindroth *et al.*[11], Volkow *et al.*[12]).

Longer reaction times during the working memory task in older women where only observed for negative, but not for positive stimuli, indicating that performance in older subjects might be enhanced when using positive stimuli, which would provide further evidence for the age-related positivity effect (Charles *et al.*[13], Mather and Knight[14], Löckenhoff and Carstensen[15], Grühn *et al.*[16], Isaacowitz *et al.*[17]). We speculate, that slowed cognitive planning in women during the Tower of Hanoi task might be related to lower spatial abilities (Voyer *et al.*[22], Finkel *et al.*[23]).

The age-related cognitive changes we report here are consistent with previous finding showing a decline across a wide range of neuropsychological domains, thereby proving the usability of our tablet-based application. Even old subjects who were not familiar with computers did not have problems understanding and performing the tasks without instruction or feedback from an experimenter. All subjects were able to complete the tests. Also, subjects of all age-groups reported that they experienced the tasks as quite enjoyable; accordingly, heightened compliance and motivation probably increased the validity of results. This point has to remain speculative, however, as we cannot provide any test-retest data or inter item reliability data.

Benefits for the experimenter included the standardized and time saving testing procedure, the secure transfer of test results to a database and facilitation of data storage and analysis.

In sum, age-related changes in cognitive functions were measured using a tablet-based application. A simple tool such as this iPad application may be a quick and effective method to screen for and track cognitive deficits in clinical and outpatient settings.

Disclosures

The authors have nothing to disclose.

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